Resistive wall wakefield and beam interactions for the femtosecond source

The transverse wakefield from the resistive wall for a circular pipe of radius b, length L, electrical conducticvity $\sigma_{conductivity}$ is given by [Handbook of Accelerator Physics and Engineering]:

$$W_1(z) = \frac{c}{\pi b^3}\sqrt{\frac{Z_0}{\pi\,\sigma_{conductivity}}}\,\frac{L}{\sqrt{z}}$$

For a charge distribution ρ(z') the wake is then:

$$W_1(z) = \frac{c\,L}{\pi b^3}\sqrt{\frac{Z_0}{\pi\,\sigma_{conductivity}}}\int_z^{\infty}\frac{\rho(z')}{\sqrt{|z-z'|}}\,dz'$$

And for a Gaussian bunch:

$$W_1(\text{bunch}, z) = \frac{c\,L}{\pi b^3}\sqrt{\frac{Z_0}{\pi\,\sigma_{conductivity}}}\,\frac{1}{\sigma_{bunch}\sqrt{2\pi}}\int_z^{\infty}\frac{e^{-\frac{z'^2}{2\sigma_{bunch}^2}}}{\sqrt{|z-z'|}}\,dz'$$

The deflecting voltage for a bunch of charge Ne, and offset y_0 is:

$$V_{transverse}(\text{bunch}, z) = N\,e\,y_0\,W_1(\text{bunch}, z)$$

And the angular deflection in a Gaussian beam of energy E (eV)is found from:

$$\Delta\,y'_1(\text{bunch}, z) = \frac{N\,e\,y_0}{E}\,\frac{c\,L}{\pi b^3}\sqrt{\frac{Z_0}{\pi\,\sigma_{conductivity}}}\,\frac{1}{\sigma_{bunch}\sqrt{2\pi}}\int_z^{\infty}\frac{e^{-\frac{z'^2}{2\sigma_{bunch}^2}}}{\sqrt{|z-z'|}}\,dz'$$

For the parameters of Table 1, the wakefields are shown together with the charge distributions for Gaussian and rectangular bunches. The deflection angles for the same parameters is also shown.

Table 1. Initial parameter set - first arc

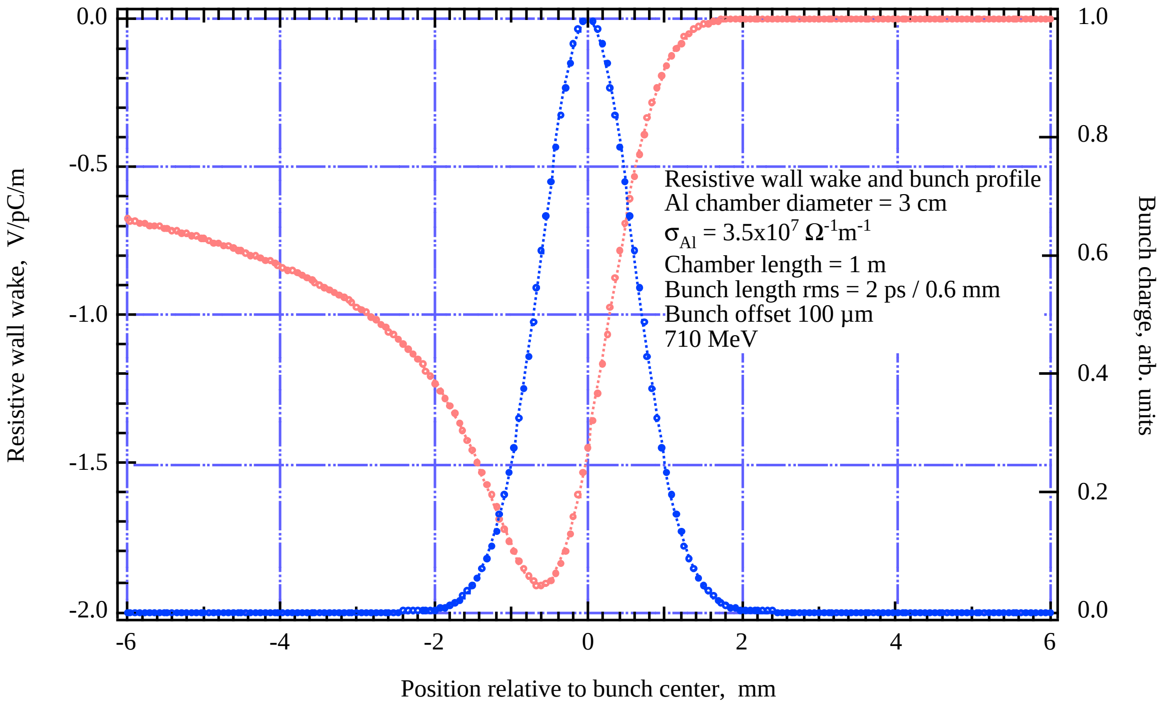
Chamber radius	1.5 cm
Chamber length	1 m
Chamber conductivity	3.5×10^7 (Al)
Bunch offset	100 µm
Number of electrons	6.24×10^9
Beam energy	710 MeV

Table 2. Vertical beam sizes

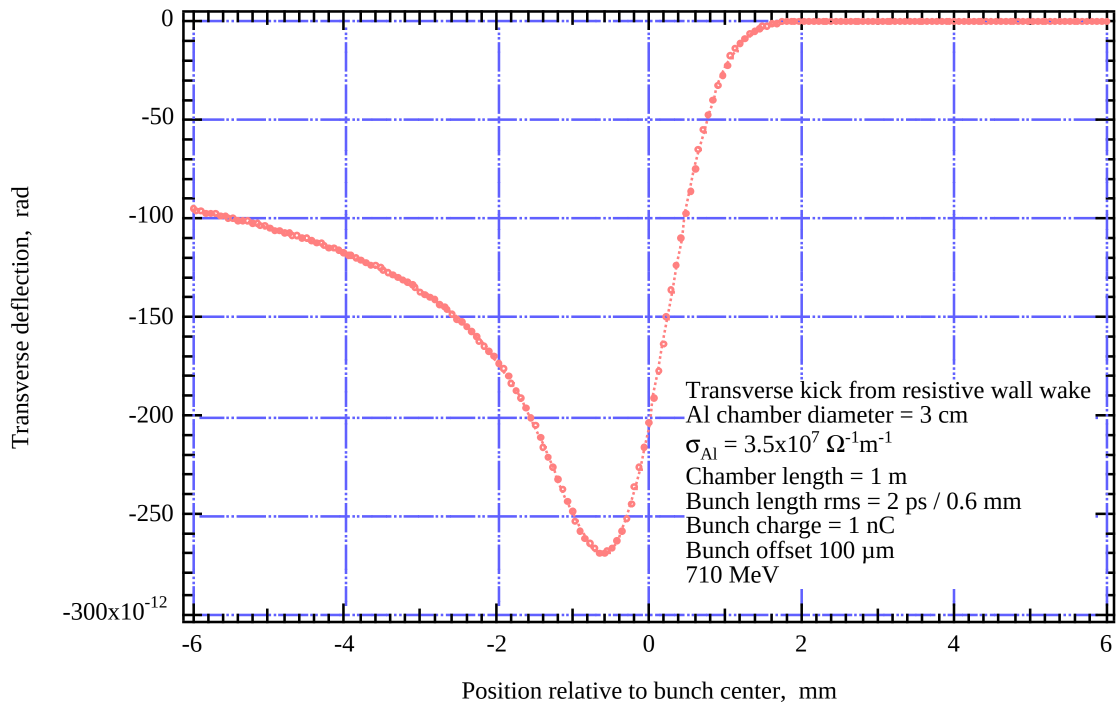
Beam emittance $\gamma\varepsilon_v$	0.4 mm-mrad
ß-function $ß_v$	10 - 30 m
	Beamsize σ_v
710 MeV	54 - 93 µm
1.3 GeV	40 - 69 µm
1.9 GeV	33 - 57 µm
2.5 GeV	28 - 50 µm

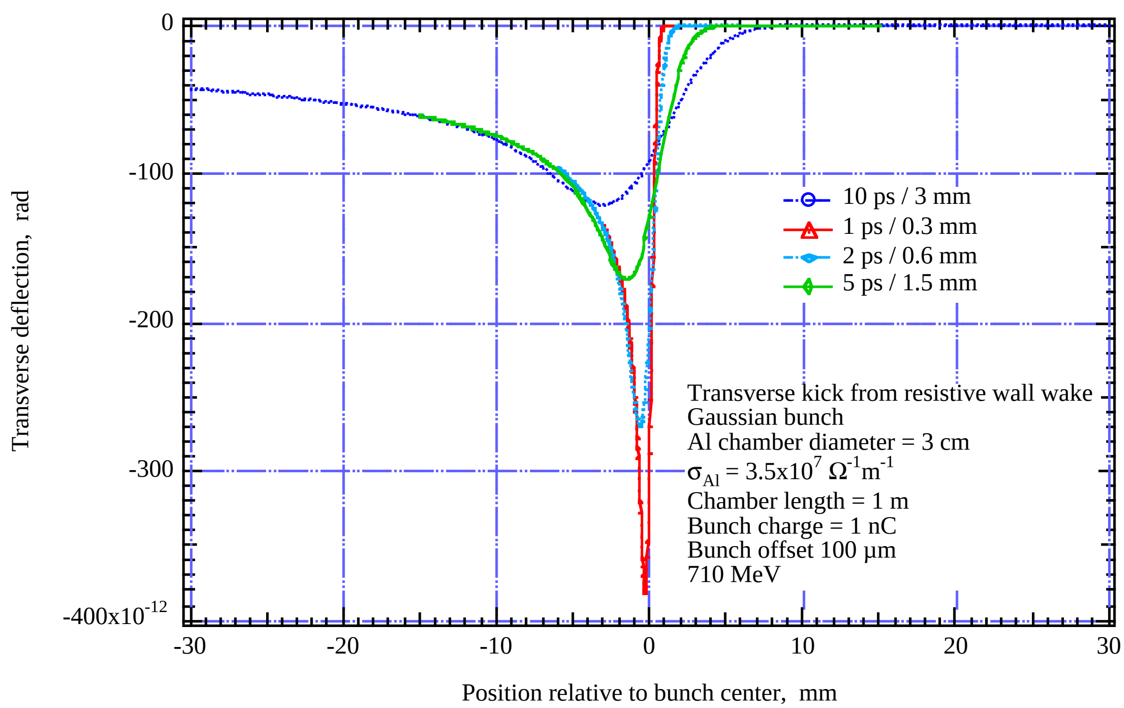
Note that the resistive wall induced kick scales as 1/E and the bunch size scales as 1/sqrt(E) - the low-energy case is the worst.

#2 - rectangular bunches



#2 - rectangular bunches





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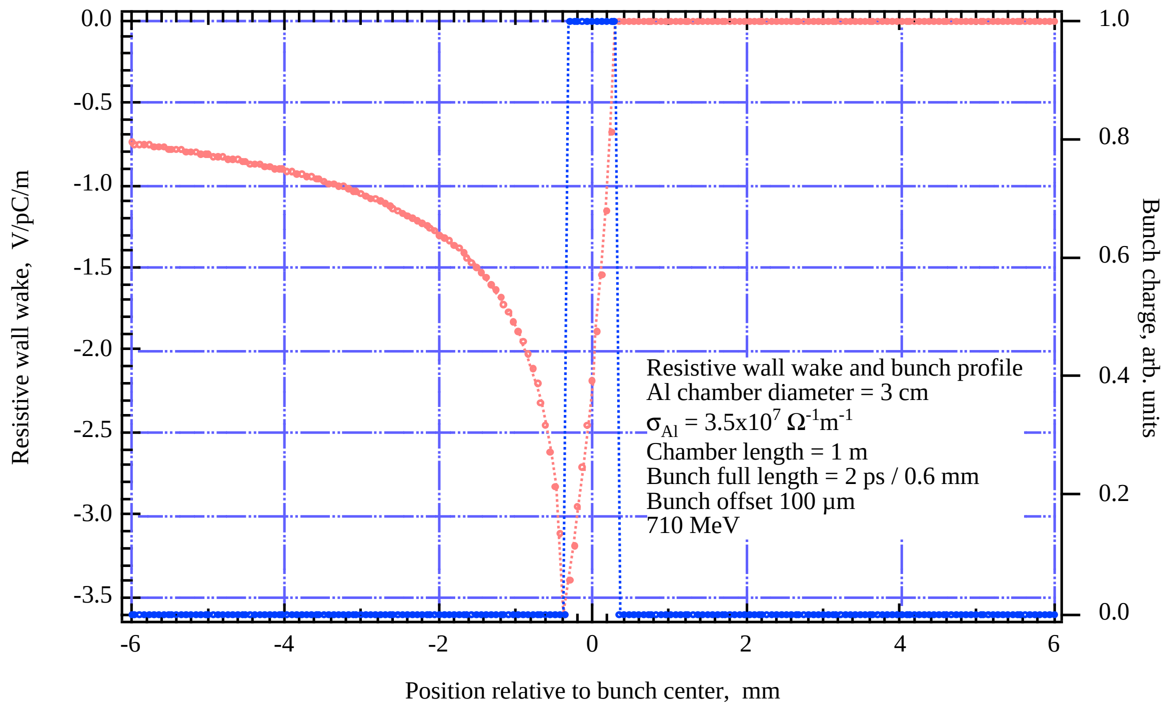

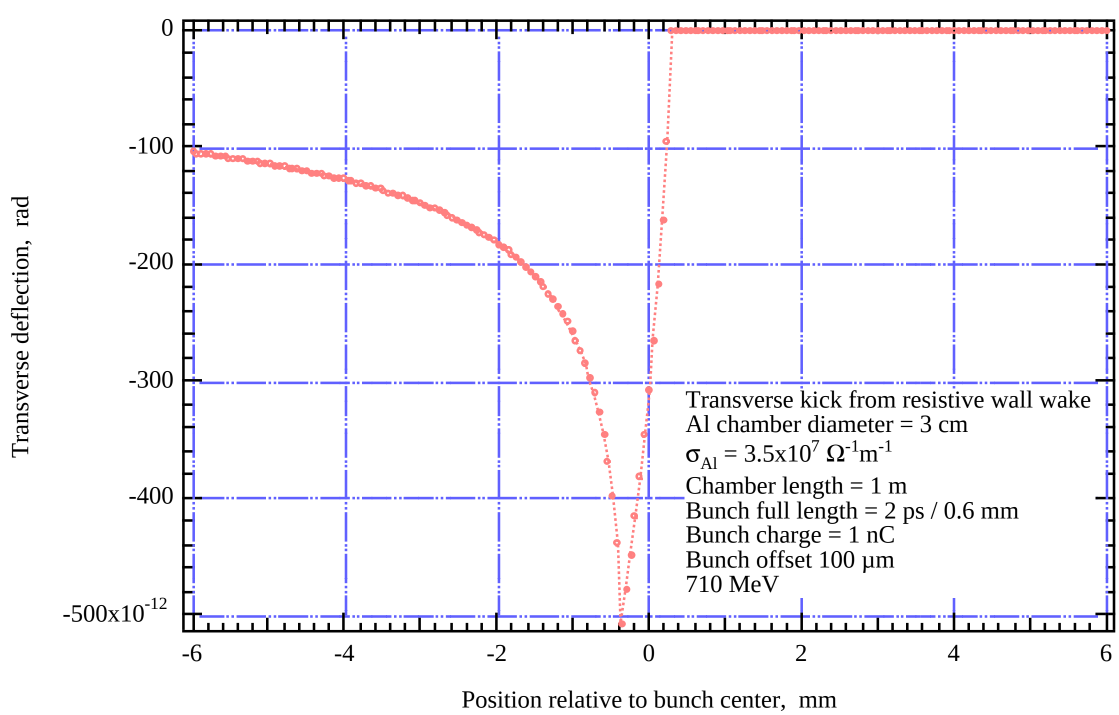

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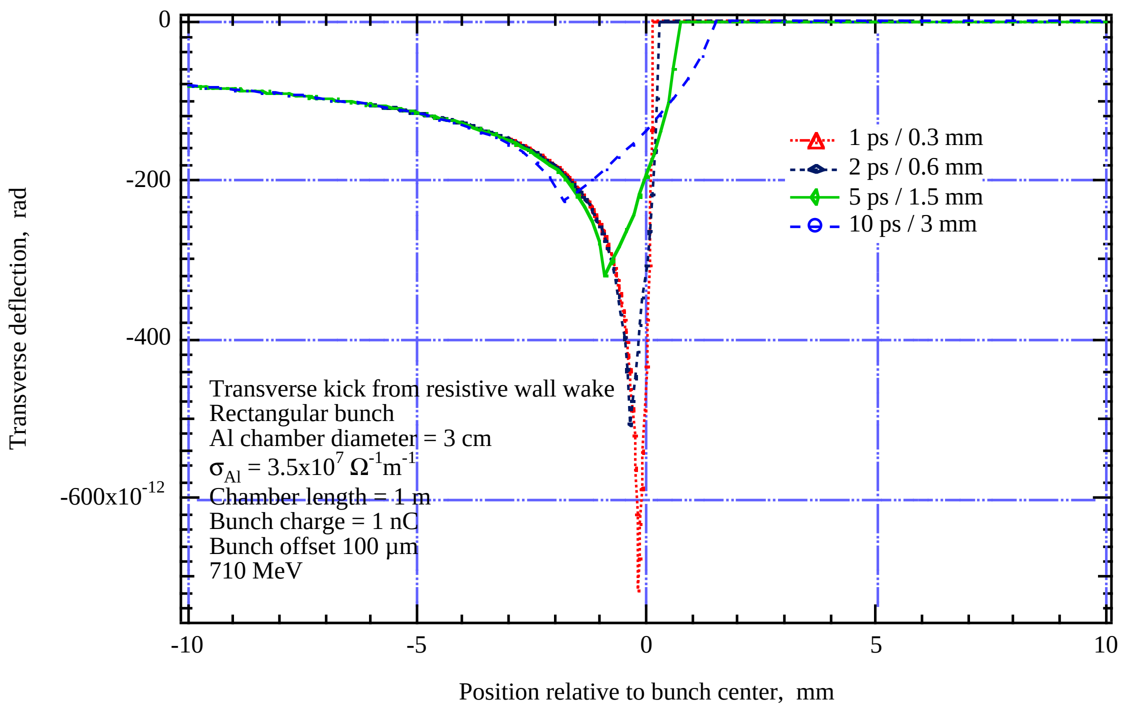


Even for the worst case of a 1 ps rectangular bunch, the distortion within the bunch arising from resistive wall transverse wakefields is less than 0.3 % of the vertical beamsize for a 200 m beampipe length. For four passes, this then becomes ~ 1%.

Since the wake scales as $1/b^3$, a reduction in beampipe diameter by a factor of 2 results in a factor 8 increase in kick.

$\sigma_{Al} = 3.5\text{x}10^7$

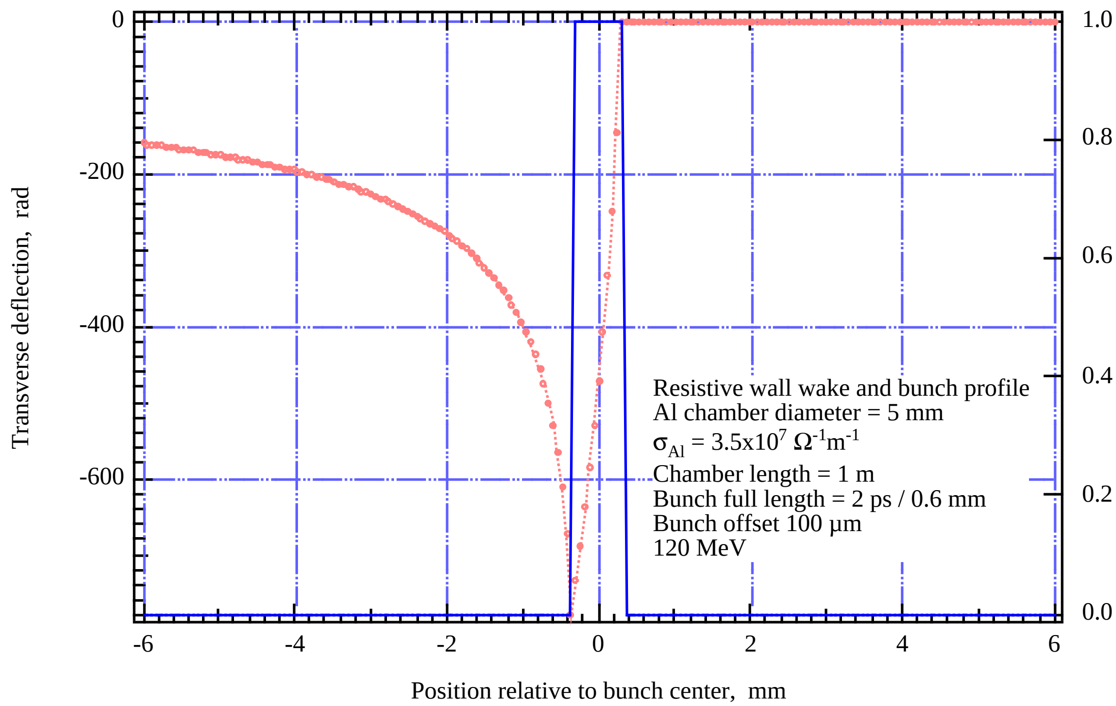
$\sigma_{Cu} = 5.6\text{x}10^7$

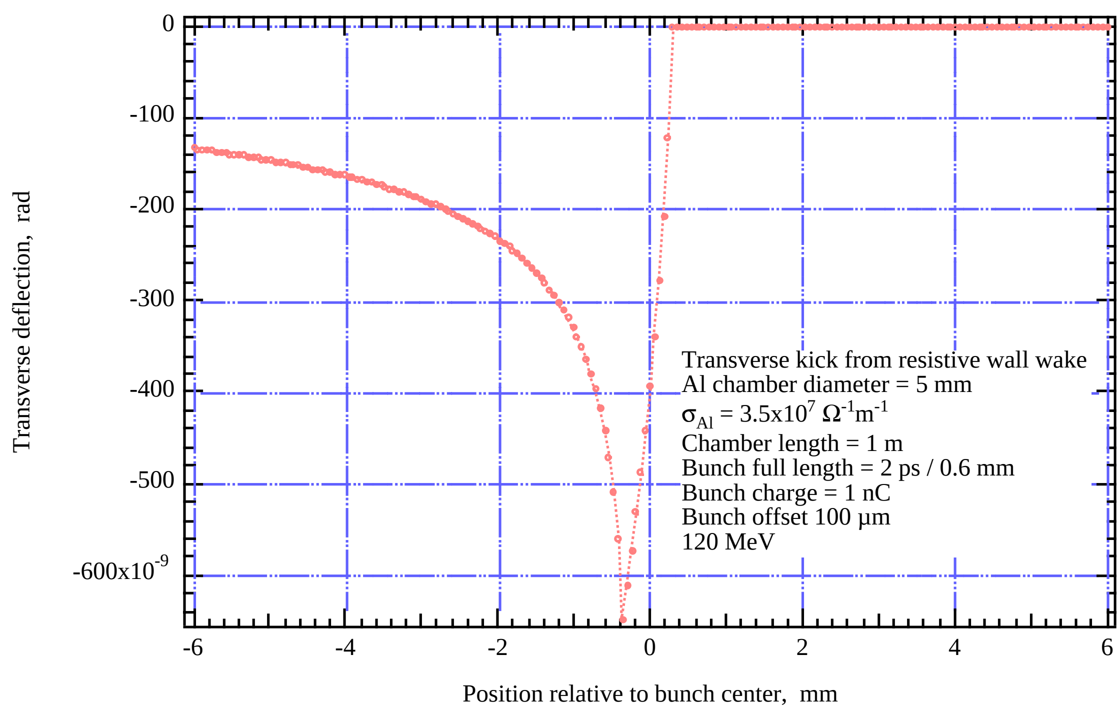
$\sigma_{St.\,St.} = 0.11\text{x}10^7$

A copper vacuum chamber reduces the kick by 25%.

A stainless steel vacuum chamber increases the kick by a factor 5.6.

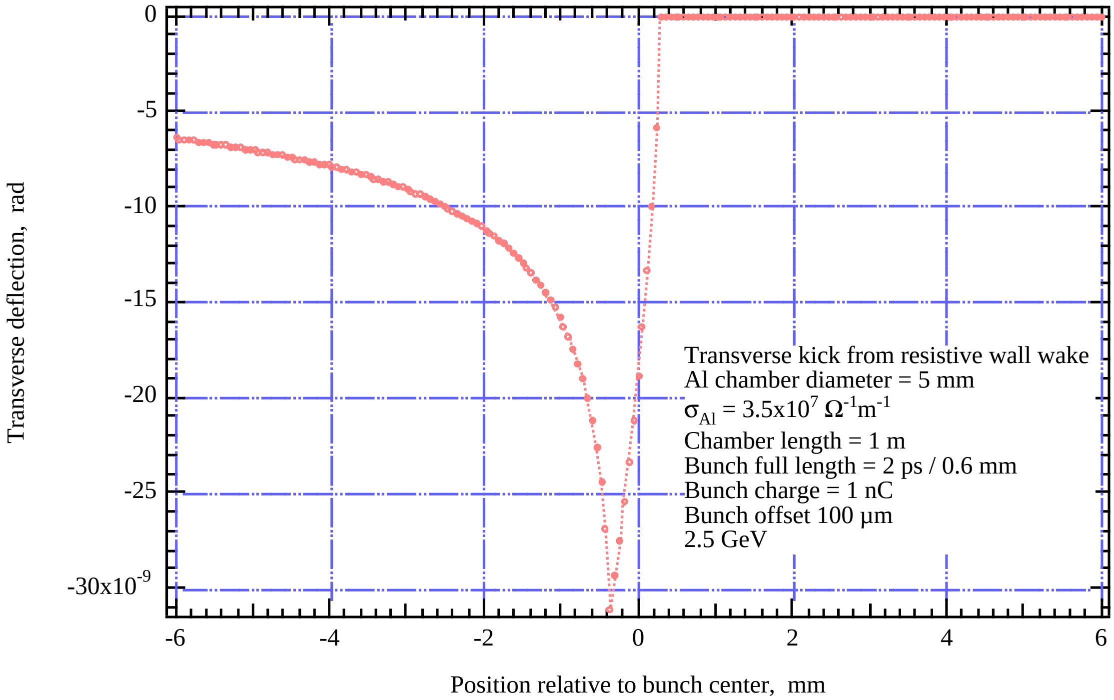
Now look at injected beam for the 2 ps rectangular bunch.

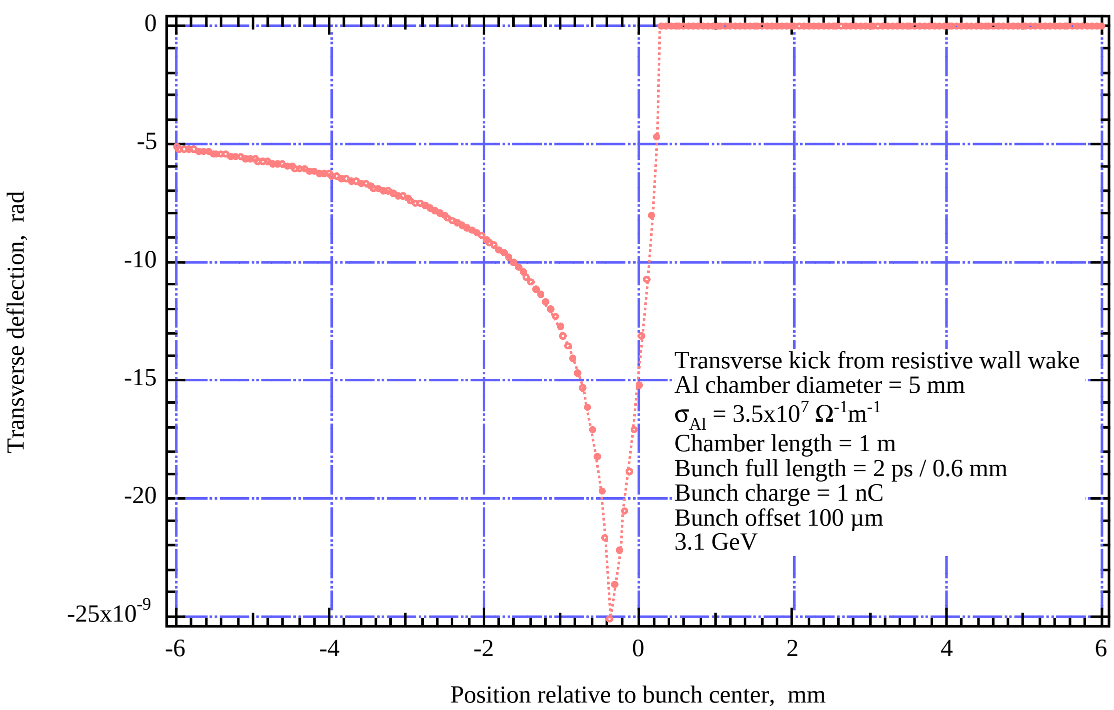




For a 50 m beampipe length, the distortion in the bunch is 25% of σ_y.

For high energies and 2 ps rectangular bunch:





This results in a distortion of 2% σ_y over 20 m of 5mm high beampipe.

We are led to the conclusion that we should open up the vacuum chamber between insertion devices to reduce this effect.
Operating with cold walls in the insertion devices will improve the situation considerably.
Beam steering through the photon production section is limited to $< \pm 100 \mu m$ from this analysis.

This analysis does not include effects from:

- Flat beampipe (20% effect)
- Focussing and ß-tron motion
- CSR or other bunch distortions
- Longitudinal effects (energy spread)
- Long-range wake (coupled bunch instabilities)